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WATERSHED HYDROLOGICAL RESPONSE TO CHANGES IN LAND USE/LAND COVERS PATTERNS OF RIVER BASIN: A REVIEW

DAMTEW FUFA TUFA[1], YERRAMSETTY ABBULU[2] & G. V. R. SRINIVASARAO[3]

[1]Research Scholar (Foreign Category), Department of Civil Engineering, College of Engineering (A), Andhra University, Visakhapatnam, Andhra Pradesh, India

[2]Associate Professor, Department of Civil Engineering, College of Engineering (A), Andhra University, Visakhapatnam, Andhra Pradesh, India

[3]Professor, Department of Civil Engineering, College of Engineering (A), Andhra University, Visakhapatnam, Andhra Pradesh, India

ABSTRACT

Land is a subset of the natural resources like water and vegetation on the earth. An imbalance among these natural resources due to human intervention brings an impact of one on another. The changes in Land use/cover (LU/C) patterns become important issues these days, considering global dynamics and their responses to environmental and socio-economic drivers. Especially in fast changing developing countries, it is a scientific challenge to predict land use changes and their effects on water availability, flood risk and erosion rates. To address these issues, catchment models are to deal with land use dynamics. An attempt has been made in this paper to study the land use/land cover changes that occur in watersheds and their effects on the hydrological system of a river basin. Also the hydrological models that are used to model impact of Land use/cover changes on water resources are identified.

KEYWORDS: Watershed, Land Use/Land Cover, Hydrological Model, Watershed Hydrology

INTRODUCTION

Today, fresh water becomes the main limiting factor in terrestrial ecosystem. The fact is that, each and every activity that has been on going in the world competes for fresh water. Freshwater availability at the global scale is an essential requirement and one of the most important challenges facing humanity at present and increasingly in the future (Schuol et. al., 2008). Other major global concerns, like food security, human health, climate change, economic development and, last but not least, regional conflicts are not exclusively but to a considerable extent related to freshwater availability. The spatial and temporal variability of watershed resources (particularly land cover change and climatic change) have a significant influence on the quantity and quality of river water flow (Legesse et.al. 2003; Bewket and Sterk, 2004).

Conversion of land to feed and shelter the growing human enterprise has been one of the primary modes for human modification of the global environment. Over the coming decades, expansion and intensification of agriculture, growth of urban areas, and extraction of timber and other natural resources will likely accelerate to satisfy demands of increasing numbers of people at higher standards of living (DeFries and Eshleman, 2004). As the watershed becomes more developed, it also becomes more hydrologically active, changing the flood volume and runoff components as well as the origin of stream flow. In turn, floods that once occurred infrequently during pre-development periods have now become

more frequent and more severe due to the transformation of the watershed from rural to more urban land uses (Daniel and Yonas, 2010).

An understanding of hydrological processes is essential for investigating impacts of land use and land cover, and climate changes on water resources. Das (2009) indicated that, water yield from a catchment depends on the amount of rainfall, watershed slope, types of soil and vegetation, and the evapotranspiration ratio.

Land cover changes commonly are highly pronounced in developing countries that are characterized by agriculture based economies and rapidly increasing human population. These changes may have immediate and long-lasting impacts on terrestrial hydrology (Calder, 1993) and alter the long term balance between rainfall and evapotranspiration and the resultant runoff. In the short-term, destructive land use change may affect the hydrological cycle either through increasing the water yield or through diminishing or even eliminating the low flow in certain circumstances (Croke et al., 2004). In the long-term the reduction in evapotranspiration and water recycling arising from land cover changes may initiate a feedback mechanism that results in a reduction of rainfall (Otieno and Anyah, 2012).

Hydrologic modelling and water resources management studies are intrinsically related to the spatial processes of the hydrologic cycle. The watershed hydrological responses are influenced by the land use and land cover patterns by partitioning rainfall between return flow to the atmosphere as evaporation and transpiration and flow to aquifers and rivers. However, techniques for the analysis of the impact of LU/C on modelled hydrological responses are still very much at early stage. The prediction of the effect of future change and validation of prediction has hardly even started (Beven, 2001; Kimaro et.al., 2005). Hence, the purpose of this review is to look at how land use land cover changes in watershed affects the hydrological system of a river basin as well as identifying hydrological models used to model the impact of Land use land cover change on river flow.

LAND USE AND LAND COVER CHANGES

Land Use and Land Cover: Definitions and Concepts

Land use refers to the intended use or management of the land cover type by human beings (FAO, 1998). It involves both the manner in which the biophysical attributes of land are manipulated and the intent underlining that manipulation (the purpose for which the land is used e.g., agriculture, grazing, etc), which are more subtle changes that affect the character of the land cover without changing its overall classification.

Land cover refers to the physical and biophysical characteristics or state of earth’s surface and immediate, captured in the distribution of vegetation, water, desert, ice and other physical features of the land, including those created solely by human activities e.g. settlements (Herold et.al., 2006). Land cover provides the most useful indicator of human interventions on the land. Land cover changes over time are a good proxy for dynamics of the earth surface resulting from a variety of drivers and factors. At a certain level, land cover provides the common ground for many actors and disciplines interested in land mapping and, thus, provides the platform to link information between them (Herold et. al. 2006). Land cover dynamics particularly-deforestation has become a global concern, as its implications for human livelihood systems are immense. It is one of the major topics in current global change studies (e.g. climate change, alteration of biochemical cycle) jointly initiated in 2002 by the International Geosphere-Biosphere Program (IGBP) and the International Human Dimension Program on Global Environment Change (IHDP) (GLP. 2005).

There are two categories through which LU/C change can be occurs; i) land use/land cover conversion and ii) land use/cover modification. Conversion refers to change from one cover or use type to another, as is the case in agricultural expansion, deforestation, or change in urban extent. Land use and land cover modification, on the other hand, involves the maintenance of broad cover or use type in the face of change in its attributes (Lambin et al., 2003).

Both conversion and modifications of land use and land cover have important environmental consequences through their impacts on soil, water, biodiversity, and microclimate, and hence, contribute to watershed degradation.

Detection of Land Use/Land Cover Change

Land Use/cover detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, land use/cover detection involves the ability to quantify temporal effects using multi-temporal data sets. Inventory and monitoring of land use/cover changes are indispensable aspects for further understanding of change mechanism and modelling the impact of change on the environment and associated ecosystems at different scales. Remote sensing is a valuable data source from which land use/cover change information can be extracted efficiently (Chen et. al., 2003). Remote sensing is defined as the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand et. al., 2008).

Many researchers those studied natural resource dynamics (environmental change, land use/cover change and forest reduction) at national, regional and local level using Remote sensing and Geographical Information System techniques to the extent possible. It is observed that, Remote Sensing and GIS is the most modern technology widely used in natural resource management and monitoring and is a helpful tool in detecting and analysing spatiotemporal land use/land cover dynamics and evaluation of land use and land cover changes at catchment levels (Mutie et.al. (2006), Ermias et.al. (2013), Ramachandra and Kumar (2004), Singh and Singh (2013), Kassa and Forch, (2007), Daniel (2008)).

Magnitude of Worldwide Land Use/Land Cover Change

Land use/cover change is also had a global character. Globally cropland area increased from 265 million hectares in 1700 to 1471 million hectares in 1990, while the area of pastureland has decreased more than six fold from 524 to 3451 million hectares (Klien Goldewijk, 2001). The increase of agricultural land took place at the expense of natural grassland. It is estimated that 4.7 million km^2 of grass land areas and 6 million km^2 of forest/woodland have been converted to cropland worldwide since 1850 (Lambin et.al., 2003), and the main purpose for land use change is to obtain food and other essentials. In Kenya, there is an increased agricultural activities replacing large portion of forests between the year 1986 and 2000. The change observed is the agricultural activities/land covering 6.55% in 1986 was intensified and expanded to 17.89% of the total land in 2000 (Otieno and Anyah, 2012). A study on land cover change in Kolar district India using supervised classification shows that there is an increasing trend (2.5%) in unproductive waste land and decline in spatial extent of vegetated area (5.33%) (Ramachandra and Kumar, 2004).

Cause of Land Use/Land Cover Changes

Land use change is largely driven by the decision of the people and population growth, declining household farm size and income (Hamza and Iyela, 2012). Whereas the natural effect such as climate change are felt only over a long period of time, the effect of human activities are immediate and often radical (Woldeamlak, 2002). The fundamental causes of LU/C as per Lambin, et al., (2003), are 1) resource scarcity leading to an increase in the pressure of production on

resources involving population of resource users, labour availability, quantity of resources, and sensitivity of resources etc, 2) changing opportunities created by markets i.e., market prices, production costs, transportation costs, and technology 3) outside policy intervention like subsidies, taxes, property rights, infrastructure, and governance 4) loss of adaptive capacity and increased vulnerability, exposure to external perturbations, sensitivity, and coping capacity and 5) changes in social organization, i.e resource access, income distribution, household features, and urban-rural interactions etc.

Land Use and Land Cover Change and its Implication in Ethiopia

In Ethiopia, land use can be seen from the perspective of human activities such as agriculture, forestry, building construction, and recently, industrialization which has led to increased human population within urban areas and depopulation of rural areas (Hamza and Iyela, 2012). The driving forces behind land use pattern include all factors that influences human activity, including local culture (food preferences), economics (demand for specific products, financial incentive), environmental condition (soil quality, terrain and moisture). Studies that have been carried out at different parts of Ethiopia indicated that croplands have expanded (Figure 1), at the expense of natural vegetation, including forests and shrub lands (Kassa and Förch (2007), Gete and Hurni (2001), Reusing (2000), Diress et.al (2010), Gerold and Negesse (2012), Daniel (2008), Daniel and Yonas (2010), and Getachew and Melesse (2012)). Land use land cover changes have negative consequences on livestock production (Gete and Hurni 2001) due to loss of the country's grazing land, change in hydrological system (Byragi and Mekonen, 2011), soil erosion, ecosystem degradation and biodiversity loss.(Daniel, 2008).

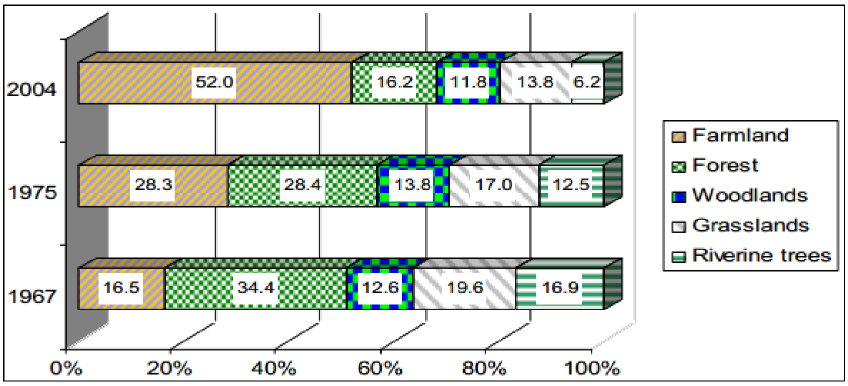

Figure 1: Land Use/Covers Change Hare Watershed in South Ethiopia (1967-2004) (Kassa and Forch, 2007)

However, most of the empirical evidences indicated that land use and land cover changes and socioeconomic dynamics have a strong relationship. As population increases the need for cultivated land, grazing land, fuel wood, settlement areas also increase to meet the growing demand for food and energy, and livestock population. Thus, population pressure, lack of awareness and weak management are considered as the major causes for the deforestation and degradation of natural resources in Ethiopia.

Watershed Hydrological Modelling in the Context of Sustainable Water Resources Management

The term "watershed hydrology" is defined as that branch of hydrology that deals with the integration of hydrologic processes at the watershed scale to determine the watershed response.

Currently, the utilization of natural resources, such as water and land, is closely interlinked with the goals of sustainability and appropriateness. The resources within a defined watershed should be utilized for the benefit of the local

population and in harmony with the environment (Förch and Schütt, 2007). Scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and protection of the environment. World Water Assessment Programme (2003) described the fact that the world faces water crises that has become increasingly clear in recent years. Challenges remain widespread and reflect severe problems in the management of water resources in many parts of the world. As a result, human health and welfare, food security, and the ecosystems on which they depend, are all at risk, unless water and land resources are managed more effectively in the present decade and beyond than they have been in the past. Moreover, these problems will intensify in the future unless effective and concerted actions are taken.

Mathematical models are attractive tools that are used to analyze the functioning of hydrology, operation, social and economic processes, as well as others that can occur in a basin, with the objective of setting and evaluating management alternatives in water resources management (Singh and Woolhiser 2002). Basically, hydrologic modelling and water resources management studies are intrinsically related to the spatial processes of the hydrologic cycle.

Hydrological modelling is a powerful technique of hydrological system investigation for both the research hydrologist and practicing water resources engineers involved in the planning and development of integrated approach for the management of water resources. Moreover, watershed modelling techniques are useful tools for investigating interactions among the various watershed components and hydrologic response analysis to LU/C and river basin management at various spatial scales (Silberstein, 2006; Refsgaard, 2007). Besides, considerable work has been undertaken in understanding and modelling the processes involved in the hydrological cycle, enabling the development of number of models to address a wide spectrum of environmental and water resources problems (Singh and Woolhiser, 2002).

Water Resource Management

Water is increasingly seen as a resource for renewable energy generation, involving construction of dams and reservoirs for hydropower, to meet increasing energy demands for enabling development and economic growth. At the same time, water is used for other major welfare issues, such as irrigation for food security and for household supply. As a consequence, some of the common problems related to water faced by many countries are shortage, quality deterioration and flood impacts, which call for a greater awareness and action. The growing pressure on the world‘s fresh water resources is mainly due to and enforced by population growth that leads to conflicts between demands for different purposes (Tessema, 2011).

Practical evidence shows that (Singh and Jain, 2002), while the world population increased by a factor of about three during the 20th century the water withdrawals have increased by a factor of about seven. Further, water of a given area can be changed in terms of quality because of human activities (Chow et. al., 1988). People till the soil, irrigate crops, fertilize land, clear forest, pump groundwater, build dams, dump water in to river and lakes, and do many other constructive and destructive things that affect the circulation and quality of water in nature.

The idea to overcome this impractical and inefficient situation in the water sector is actually more than six decades old but had only a dubious record of implementation until recently. An appropriate way to handle the question of water is to use a single system of water management, which is built up by river basin, in an integrated way. The Global Water Partnership (UNEP, 2009) defines Integrated Water Resources Management (IWRM) as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems, and

emphasized that water should be managed in a basin-wide context, under the principles of good governance and public participation.

As a principal motivating and integrating factor in hydrologic response studies, water must be managed in the full understanding of its importance for social and economic development, using improved water resources management tools based on sound scientific principles. The tools have to involve, amongst others, an integrated description of the land phase of the hydrological cycle, an integrated description of water quantity, quality and ecology, an integration of hydrological, ecological and economical information designed for decision makers at different levels (Abbot and Refsagaard, 1996).

Hydrologic Models

The integrated water resource management is both the technology-based management and non-technology based management (Singh and Frevert, 2002). The core of technology based management is watershed hydrology modelling. Watershed hydrologic models are mathematical representation of hydrologic processes. It consists of computing stream flows and in some cases associated sediment or other water quality constituent load that results from precipitation runoff (Wurbs and James, 2002; Beven, 2001).

Watershed hydrologic models have been developed for many different reasons and therefore have many different forms. However, they are in general designed to meet one of the two primary objectives. One objective of watershed modelling is to gain a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may affect these phenomena. Another objective of watershed modelling is the generation of synthetic sequences of hydrologic data for facility design or for use in forecasting. They also provide valuable information for studying the potential impacts of changes in land use or climate (Wurbs and James, 2002).

Hydrologic Model Classification

Watershed models can be classified according to different criteria that may encompass process description, time scale, space scale and technique of solution (Singh and Woolhiser 2002). Depending upon the way the hydrological processes are described, the models can also be classified as deterministic, stochastic, or mixed (Singh, 1995). In a deterministic model, outcomes are precisely determined through known relationships among states and events, without any room for random variation.

On the other hand, if a model has at least one component of random character which is not explicit in the model input, but only implicit or “hidden” it is called stochastic model. If the model components are described by a mix of deterministic and stochastic components, the model is called stochastic-deterministic or hybrid model. On the basis of process description, the hydrological models can be classified into three main categories: lumped models, semi-distributed models and distributed models (Džubáková, 2010, Singh and Frevert, 2002).

Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. Most of such models are not capable of representing all hydrologic processes for investigating the impacts of land use and climate change on the hydrological regime (Beven, 2001). Physically-bases distributed models on the other hand fully allow parameters to vary in space at a resolution usually chosen by the user. Distributed modelling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behaviour.

However, the major constraint is the extensive data requirements, since all parameters that correspond to each modelling unit are assumed to be measurable from the field. These models tend to have good explanatory depth but low predictive power (Mulligan and Wainwright, 2004). Semi-distributed (simplified distributed) models partially allow parameters to vary in space by dividing the basin into a number of smaller sub-basins. The main advantage of these models is that their structure is more physically-based than the structure of lumped models, and that they are less demanding on input data than fully distributed models. SWAT, HEC-HMS, HSPF, PRMS, DWSM, TOPMODEL and HBV, are considered as semi-distributed models.

Model Selection Criteria

Models are differing in terms of complexity, processes considered, and the data required for model calibration and model use. In general there is no 'best' model for all applications (Merritt et al., 2003). The selection of a particular model is a key issue to get satisfactory answers to a given problem. Currently, there are numerous hydrological models simulating the hydrological process at different spatial and temporal scales. Singh and Frevert (2002) describe five criteria for hydrological model selection 1) representativeness 2) comprehensiveness 3) applicability and 4) connectivity 5) geographical representativeness and the most appropriate model, generally depends on the intended use and the characteristics of the catchment being considered (Merritt et al., 2003).

Model Calibration, Validation and Sensitivity Analysis

The availability of concurrent runoff and climate data primarily dictated the selection of time period used for model calibration and validation. Calibration is a process of parameter adjustment (automatic or manual), until observed and calculated output time- series show a sufficiently high degree of similarity (Wagener et.al., 2003), and watershed hydrological modelling consists of three procedural steps, (1) Selection or development of a model structure, and subsequently computer code, to represent the conceptualisation of the hydrologic system which the hydrologist has established in his or her mind for the watershed under study. (2) Calibration of the selected model structure, i.e. estimation of the 'best' parameter set (s) with respect to one or more (often combined) criteria. (3) Validation or verification of this model by applying it to a data set not used in the calibration stage.

Validation is the step where the capabilities of the calibrated model in simulating acceptable results could be confirmed. It involves testing the ability of a model to simulate the hydrologic response of a basin for a conditions different from that used during the calibration period (Legesse et.al., 2003; Mutie et.al., 2006; Tessema 2011).

Sensitivity analysis is the step where the uncertainties of the modelling process, either due to model structure or the estimated parameter values, could be evaluated. A sensitive parameter, in river flow modelling study, is one that changed the model outputs of the stream flow significantly per unit change in its value (Tessema, 2011). Eight parameters out of 27 SWAT model parameters that highly affect the stream flow in upper Awash River basin are identified using Latin Hypercube One-factor-At-a-Time techniques (Tessema, 2011). Legesse et.al. (2010) also reported that, the basin response is more sensitive to the rainfall correction factor (RAIN ADJ), a monthly temperature adjustment factor for calculation of PET (jh coef), soil moisture related parameter SOIL MOIST MAX and subsurface flow related parameter SSRCOEF LIN and surface runoff related parameter CAREA MAX at Meki river basin.

Impacts of Land Use/Land Cover Changes on Watershed

Land surface characteristics, e.g. surface roughness, albedo, and moisture availability, strongly control land-atmosphere interactions. Through turbulence, these surface conditions play a major role in the transfer of mass, momentum, and heat in the Planetary Boundary Layer (PBL). The PBL provides a vital physical link between the atmosphere and the surface of the earth for the exchanges of heat, moisture, and momentum fluxes (Otieno and Anyah 2012). Land use/cover is a biophysical characteristic that have strong interrelation between atmosphere and ground surface hydrologic cycle. Its impact is direct on climate and water resources on the ground.

Impacts on Hydrology

Land use/ cover changes have been responsible for altering the hydrologic response of watershed leading to impacting river flow (Getachew and Melesse 2012).

Land under little vegetation cover (woldeamlak, 2002), is subjected to high surface runoff and low water retention. Legesse et.al. (2003) reported that vegetation cover increase evapotranspiration and decrease in the mean annual river flow. In other word, increasing forest cover would substantially reduce sediment yield and modulate stream flow (Kigir et. al., 2010). In addition, changing vegetation results in different runoff curve number (RCN) which results in changes in rainfall runoff response (Mutie et. al., 2006). Therefore, land cover changes interfere with the land phase of hydrologic cycle (Figure 2). The competing processes may result in either increased or reduced dry season flows (Calder, 2002). Effects on dry season flows are likely to be very site specific. It cannot be assumed that it is generally true that afforestation will increase dry season flows.

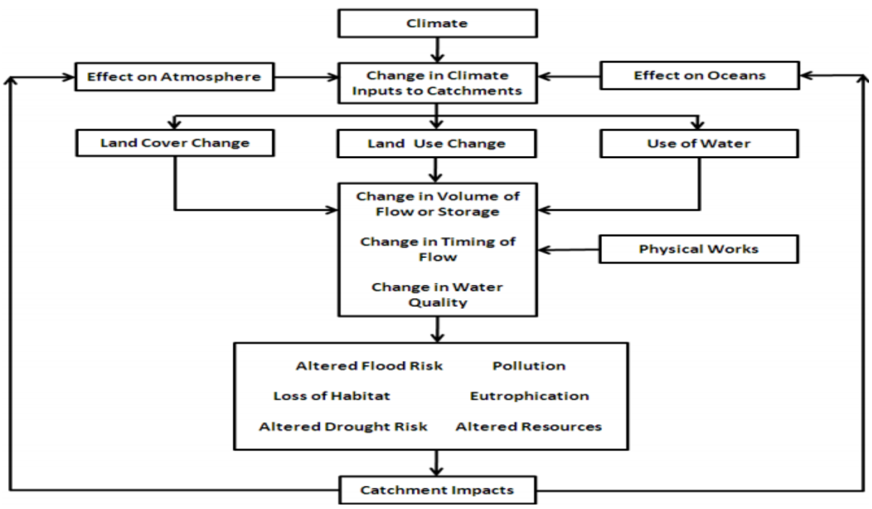

Figure 2: Follow Chart that Show Hydrological Impact Concepts of a Watershed (Deogratias, 2011)

Impacts on Climate

Land use/cover is a biophysical characteristic that have strong interrelation between atmosphere and ground surface hydrologic cycle. Its impact is direct on climate and water resources on the ground. expansion of agriculture in to forested area lead to a modest reduction in monthly rainfall total and also may contributing to notable shift in moisture zones and centres of rainfall maxima (Otieno and Anyah, 2012). The climate and CO_2-induced changes in vegetation composition and density between 2100 and 2000 could lead to decreases in summer afternoon surface ozone of up to 10

ppb (Wu et.al. 2012). Vegetation cover affects local regional and global atmospheric temperature thereby affect hydrologic cycle.

Impacts on Soil Erosion

The consequence of land use/land cover change triggers (Gete and Hurni, 2001), three important process that aggravate soil erosion. First because of intensification, the physical hydrological properties of the soil were badly affected. Second, at the onset of rainfall, about 77%of the area bare exposed to erosive power of rainfall. Third, almost all steep slopes, even those >100%, are under cultivation. Land cover is one of the factors that determine the rate of soil loss due to erosion. It influences both the erosive of the eroding agents and the erodibility of the eroding subject (Morgan, 1995).

CONCLUSIONS

Most of the problems encountered in the water sector today arise from the conflicting issues of water usage and allocation. The increase of population and dry spell causing water shortages regularly in many areas, result in allocation issues and conflicting rights over the limited water resources.

The attitude "first in time priority is right" may no longer be an equitable approach in resolving such conflicts. In view of the growing scarcity of water resources for irrigation in some basins and the felt need for effective measures to resolve water shortages and improve water usage, consideration of an alternative approach based on deficit irrigation principles is to be advocated.

Land cover dynamics in particular, deforestation has become a global concern, as its implications for human livelihood systems are immense. Land use change is largely driven by the decision of the people and population growth, declining household farm size and income. Whereas natural effect such as climate change are felt only over a long period of time, the effect of human activities are immediate and often radical. Land use land cover is a biophysical characteristic that have strong interrelation between atmosphere and ground surface hydrologic cycle. Its impact is direct on climate and water resources on the ground.

The use of hydrological models has therefore been of interest for integrated water resources management. Specifically, in order to properly quantify integrated effects of a changing land use and climate with high spatial and temporal resolution, the models have to fulfil certain criteria. They should be simple enough to work on large scales, with sparse data and future climate scenarios. This is especially important for the application in developing countries. Though much research evidence revealed that reduction in natural vegetation cover increases runoff in wet season and reduce base flow in dry season, others believed that as vegetation increases, water loses through evapotranspiration causing a reduction in base flow.

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